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1929-1931

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VOLUME VI

PART 1

PLANKTON OF THE AUSTRALIAN-ANTARCTIC QUADRANT

PART 1. NET-PLANKTON VOLUME DETERMINATION

By

KEITH SHEARD

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PART 1

PLANKTON OF THE AUSTRALIAN-ANTARCTIC QUADRANT

PART 1. NET-PLANKTON VOLUME DETERMINATION

By

KEITH SHEARD

[B.A.N.Z.A.R.E. Reports, Series B, Vol. VI, Part 1, Pages 1-20]

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PLANKTON OF THE AUSTRALIAN-ANTARCTIC QUADRANT

PART 1. NET-PLANKTON VOLUME DETERMINATION*

By KEITH SHEARD.

Division of Fisheries, Council for Scientific and Industrial Research.

(Tables 1–16).

Acknowledgments

I am indebted to Sir Douglas Mawson and Professor T. Harvey Johnston for making the collection available to me; to Professor W. Dakin and Mr. A. N. Colefax (to whom it had been previously entrusted) for releasing it; to Dr. Harold Thompson, Chief of the Division of Fisheries, C.S. and I.R., for his ready permission to include the work in my activities; and to Miss P. Kott and Mr. R. Kenny of the Department of Biology, the University of Western Australia, for their assistance in assessing and sorting the material.

Sources of Material

The data are drawn from portion of the material detailed in the Biological Organization and Station List (T. Harvey Johnston, 1937), together (for the purposes of comparison of the settlement and displacement volume methods) with volume results from the Cronulla plankton 1943–44, C.S.I.R. Division of Fisheries; the hydrological data are taken from the B.A.N.Z.A.R.E. papers on Hydrology (A. Howard and H. V. Sverdrup, 1940).

Introduction

This report consists of:

(A) A brief discussion of the relative merits of the displacement and settlement methods of assessing plankton volume.

(B) A review of the volumes of the plankton taken by the B.A.N.Z.A.R.E. N 70 net hauls.

(C) A brief comparison between the net plankton unit volumes found in Australian and Antarctic waters and those published elsewhere.

A. Comparison of Settlement and Displacement Methods

Among methods of obtaining an estimate of plankton mass, both the settlement and displacement techniques of assessing wet volumes are used. They fill the need for estimates, which are easy and time-saving to make, and which do not involve damage to the organisms concerned.

*Contribution No. 57 from the Marine Biological Laboratory, C.S.I.R. Division of Fisheries, Cronulla, New South Wales.

Direct counts are laborious and time-consuming, while the various direct methods of determining elements and compounds result in the destruction of material from which other useful data might have been obtained at some later date. Such determinations are, of course, valuable and, for some purposes, obligatory. However, estimates of wet volumes could be of use as a preliminary routine for investigating general trends and for making comparisons (with due regard to biological and other factors).

Hardy and Gunther (1935, 69) criticized the settlement method, and some workers (Bigelow and Sears, 1939; Clarke, 1940; and Redfield, 1941) have urged the superiority of the displacement method over the settlement method; others (Sverdrup, Johnson and Fleming, 1942) apparently consider them of equal reliability. In Kesteven (1942) the values which have been subjected to statistical analysis were obtained by the use of the settlement method. Those discussed (in conjunction with counts of organisms) by Russell (1934) were similarly derived. Other workers (Bigelow and Sears, 1939, 225; Redfield, 1941, 89; Sverdrup, Johnson and Fleming, 1942, 928 and Table 101) apparently consider that a conversion factor can be found which permits of the comparison of volumes obtained by either method. Moberg (1925) arrived at a dry plankton settlement volume conversion factor 1/3·1, probable error ± 1·0.

Accordingly, it appeared worthwhile to estimate the volumes of the N 70 vertical and N 70 horizontal hauls of the B.A.N.Z.A.R.E. 1930–1931, and those of the Cronulla Station (N 70 horizontal of the C.S.I.R. Division of Fisheries for 1943 and 1944, using both methods (Tables I and II).

In addition, a limited series of tests were made on selected material, a test was made of the effect of cylinder diameter on the settlement volume recorded from a given displacement volume (Tables IV to VII), repeat trials (10 for each method) were made on a single sample, in each case carrying out the whole procedure to test the degree of variation obtained by each method (see text), and a test of the total water in unlike plankton masses was made by the method of Dean and Stark (Lowndes and Panikkar, 1941) (Table III).

Methods.

As it was suspected that settlement volumes varied with the diameter of the container (see Table VI), cylinders of 5 cm. diameter were used throughout. The material was allowed to stand for 24 hours. In practice, it was found that the supernatant liquid was clear at this stage and that subsequent standing for periods of up to 7 days did not change the apparent volume beyond the reading error of the apparatus.

The displacement volumes were assessed by filtering the mass through filter paper (taking care to wet only the bottom portion of the paper in the process). This was allowed to drain for four hours, the mass being then washed with a measured quantity of water into a measured quantity of water. The volume was then obtained by difference. It was found that this method gave slightly more consistent results than those obtained by the simpler one of; (a) measuring the volume of the plankton and water mixed; (b) filtering off the water; (c) measuring the amount of liquid obtained (Clarke, 1940). However, the difference is small, and comparisons between the results obtained by the two methods are valid.

Although in practice it is necessary to filter off the plankton in the displacement method through a mesh only a few degrees finer than that used in the catching net, as a precaution the material was filtered through Postlip 633 mill filter paper.

Relation of settlement and displacement volumes (Tables I and II).

In dealing with the Cronulla and B.A.N.Z.A.R.E. N 70 tow nettings, the volume of each has been estimated by both the displacement and settlement methods. Anticipating the results of the settlement volume variation tests the results are summarized in Table I where the settlement volumes are arrayed against the respective displacement volumes, 197 separate samples are represented.

TABLE I.

Comparison of Displacement and Settlement Volumes (ml.).

N 70 Tow nettings.

No. of Hauls.	Displacement Volume (ml.).	Settlement Volume (ml.)*	No. of Hauls.	Displacement Volume (ml.).	Settlement Volume (ml.)
13	1	3(3) 4(3) 5 6 7 8 10(3)	2	37	102 104
24	2	2(3) 3(2) 4(2) 5(4) 6(3) 7 8(2) 9(2) 10(2) 11 12 15	3	40	142 160 178
			1	48	131
20	3	4(4) 5(3) 6(4) 7(2) 8 10(2) 12(2) 13 18	1	50	170
			1	57	185
13	4	7 8 9(2) 10(3) 11 12(2) 16 20 25	1	60	380
16	5	5(2) 10(4) 15(6) 16 20 30 50	1	62	136
9	6	12 14 15 16 20(2) 30 34 108	1	65	360
8	7	10 11 15 18 20 25 26 42	2	72	180 223
10	8	12 13 16 17 18 19(2) 30 46 52	1	82	251
5	9	20 22(2) 27 30	1	110	230
9	10	15 20 22 24 30(3) 35 55	1	120	1150
4	11	25 30 40 44	1	125	150
4	12	28 32 50 60	1	142	236
1	13	70	2	150	300 575
4	14	29 38(2) 40	1	175	385
3	15	38 40 90	1	182	400
1	16	53	1	184	440
6	18	26 32(2) 48 50 105	1	225	690
1	20	70	1	250	350
2	22	57 60	2	300	415 850
1	24	62	1	330	580
4	25	70 95 165 295	1	350	1250
1	27	125	1	352	1175
1	28	100	1	360	1150
1	32	110	1	400	940
1	34	130	1	1000	1800
2	35	95 150			

* The figure in brackets represents the number of times a particular settlement volume was obtained from hauls of the given displacement volume.

The table should be read: of 13 hauls each giving a displacement volume of 1 ml. the settlement volumes were those shown, and so on.

The ratio settlement to displacement volume has been calculated and arrayed against the corresponding displacement volume (Table II).

A consideration of these tables suggests that, while some general overall relation might exist between settlement and displacement volume, the wide range of settlement values associated with a particular displacement value renders the calculation of a conversion factor and the use of this to equate single pairs of values a practice of very doubtful merit.

TABLE II.

Displacement volumes and $\frac{Settlement}{Displacement}$ *Ratios.*

N 70 Tow nettings.

No. of Hauls.	Displacement Vols.	Ratio $\frac{Sv}{Dv}$	No. of Hauls.	Displacement Vols.	Ratio $\frac{Sv}{Dv}$
13	1	3·0(3) 4·0(3) 5·0 6·0 7·0 8·0 10·0(3)*	1	32	3·4
			1	34	3·8
24	2	1·0(3) 1·5(2) 2·0(2) 2·5(4) 3·0(3) 3·5 4·0(2) 4·5(2) 5·0(2) 5·5 6·0 7·5	2	35	2·7 4·3
			2	37	2·8 2·8
			3	40	3·5 4·0 4·4
20	3	1·3(4) 1·7(3) 2·0(4) 2·3(2) 2·7 3·3(2) 4·0(2) 4·3 6·0	1	48	2·7
			1	50	3·2
13	4	1·7 2·0 2·2(2) 2·5(3) 2·7 3·0(2) 4·0 5·0 6·2	1	57	3·2
			1	60	6·3
16	5	1·0(2) 2·0(4) 3·0(6) 3·2 4·0 5·0 10·0	1	62	2·2
			1	65	5·5
9	6	2·0 2·3 2·5 2·7 3·3(2) 5·0 5·7 18	2	72	2·5 3·1
			1	82	3·1
8	7	1·4 1·7 2·1 2·6 3·5 3·7 6·0	1	110	2·1
10	8	1·5 1·6 2·0 2·1 2·2 2·4(2) 3·7 5·7 6·5	1	120	9·6
			1	125	1·2
5	9	2·2 2·5(2) 3·0 3·3	1	142	1·7
9	10	1·5 2·0 2·2 2·4 3·0(3) 3·5 5·5	2	150	2·0 3·8
4	11	2·3 2·7 3·6 4·0	1	175	2·2
4	12	2·3 2·7 4·2 5·0	1	182	2·2
1	13	5·4	1	184	2·4
4	14	2·1 2·7(2) 2·8	1	225	3·1
3	15	2·5 2·7 6·0	1	250	1·4
1	16	3·3	2	300	1·4 2·8
6	18	1·4 1·8(2) 2·7 2·8 5·6	1	330	1·7
1	20	3·5	1	350	3·6
2	22	2·6 2·7	1	352	3·3
1	24	2·6	1	360	3·2
4	25	2·8 3·8 6·6 7·8	1	400	2·3
1	27	4·6	1	1000	1·8
1	28	3·6			

* The figure in brackets represents the number of times the ratio was obtained in relation to a given displacement volume.

The hauls measured cover all types of plankton proper from pure phytoplankton, mixed plankton to pure zooplankton, representing the range of material normally encountered.

For instance the value of the conversion factor for the hauls dealt with here would be 3·3 with a little over 50 per cent. of the values lying between 2 and 4·5 (Bigelow and Sears, 1939, use 2; and Redfield, 1941, considers a factor of 4·9). An attempt to apply any of these values back to an individual case involves a common statistical fallacy, particularly as no two hauls were alike in phyto- or zoo-plankton composition.

Repeated test on a single sample.

(1) A sample of mixed copepod zooplankton containing no phytoplankton was dried as for the displacement method and the displacement volume found. The process was repeated ten times, in each case the material being removed from the fllter paper under a low power binocular microscope.

The displacement volumes recorded varied from 28·0 ml. to 28·5 ml. over the ten trials, a variation of 1·8 per cent. A special reading scale was constructed and the grouping of the readings was 28·0 (1), 28·15 (3), 28·25 (3), 28·35 (1), 28·4 (2), 28·5 (1).

(2) The same sample was taken and shaken in a cylinder to obtain the settlement volume, being allowed to stand for 48 hours in a balance room reasonably free from vibration before each reading. The sample was well shaken at each trial and ten readings were made in a cylinder of 5 cm. diameter.

The settlement volumes recorded ranged from 93·0 ml. to 96·5 ml., a range of 3·6 per cent. The grouping of the readings was 93·0 (1), 94·0 (2), 94·5 (2), 95 (4), 96·5 (1).

This test, in which variation due to the sampling of plankton masses of different composition was ruled out, indicates the possibility of a slightly greater error implicit in the settlement volume technique, due possibly to varying positions of individuals of different falling weight. In each of the ten settlement tests check readings were made at 24 hours. There was no alteration in the recorded volume at 48 hours.

Water content of displacement dried plankton (Table III).

Three 10·00 gm. samples of a displacement dried copepod plankton (chiefly *Drepanopus pectinatus* Brady) and three 10·00 gm. samples of displacement dried phytoplankton were tested for total water content, ground, dried at 60° C. for 48 hours, weighed, and then ashed and re-weighed (Riley, 1914, 6).

The water extraction method used was that of Dean and Spark (Lowndes and Panikkar, 1941).

TABLE III.

Water content (xylol extracted), and ash weights.

	Copepod (*Drepanopus*).			Phytoplankton.		
	A.	B.	C.	D.	E.	F.
Wet weight	10·00	10·00	10·00	10·00	10·00	10·00 gm.
Displacement	9·50	9·50	9·55	9·60	9·55	9·70 ml.
Total water	8·65	8·55	8·58	8·80	8·90	8·90 ml.
Dry residue	·45	·44	·47	·47	·45	·46 gm.
Ash	·27	·27	·26	·30	·30	·31 gm.
$\frac{\text{Dry plankton (mg.)}}{\text{Displacement Vol. (ml.)}}$	·0211	·0216	·0203	·0204	·0212	·021
$\frac{\text{Wet weight (mg.)}}{\text{Displacement Vol. (ml.)}}$	1052	1052	1047	1040	1047	1030

The results indicate:

(1) That the total retained water using the filtration method is reasonably constant in relation to the wet weights of the two dissimilar plankton masses.

(2) The total retained water is reasonably constant in relation to the dry and ash weights.

(3) Although the plankton equivalents entered in the table are reasonably consistent among themselves they are of a different order from those found by Riley (1939 and 1941). This may be due to the intervention of the Xylol treatment. Further work on these equivalents is indicated.

Effect of cylinder diameter on settlement volumes (Table IV).

Using a total water height of 21 cm. a copepod sample (*Drepanopus pectinatus* Brady) of 30·0 gm. wet weight, 28·5 ml. displacement volume, was tested in each of four cylinders of different diameter.

Although the trials were not repeated to test the method variation the results suggest an inverse relationship between the area of the cross-section of the cylinder employed and the resulting settlement volume obtained. If the pressure of the plankton in the cylinder (measured by the height of the plankton) were a major factor, a relatively lower settlement volume could be expected, at least in the narrowest cylinder as against the widest. Instead a packing effect apparently occurs as the individual is freer to be aligned horizontally in the wider cylinder.

TABLE IV.

Copepod sample (Drepanopus, *ca. 1 mm.*).

Wet Weight 30·0 gm.

Container diameter	21·0	21·0	21·0	21·0 cm.
Height water plus plankton	3·0	5·0	6·0	8·0 cm.
Height of plankton	14·1	4·8	3·2	1·6 cm.
Settlement volume	100	95	90	82 ml.

Read after standing two days. Reading error—Settlement volumes ± ·5 ml.

The range of the volume for the same sample, of 18 ml. within the limits of 10 ml. and 82 ml. is well outside the range shown in the earliest test. Values obtained are apparently unduly affected by the width of the cylinder used.

Comparison of volume of different wet weights of a like sample (Table V).

A sample of a pure copepod catch (*Drepanopus pectinatus*) was well mixed and filtered to displacement volume dryness.

Four subsamples (10 gm., 20 gm., 30 gm., 40 gm.) were taken and the volumes found by both methods.

The results show that, for the samples taken:

(1) The displacement volumes are directly proportional to the wet weights.

(2) The agreement between the increase in the wet weight and the increase of the settlement volume is not good.

(3) As noted by Redfield, (1941, 89) the ratio $\frac{Sv}{Dv}$ is smaller with the larger samples.

TABLE V.

Comparison of volumes of wet weights pure Copepod (Drepanopus).

Wet weight	10 gm.	20 gm.	30 gm.	40 gm.
Displacement volume	9·5	19	28·5	37 ml.
Settlement volume	37·5	69	100·5	106 ml.
Ratio $\frac{Sv}{Dv}$	3·94	3·63	3·52	2·86

Reading error { Displacement volumes ± ·25 ml.
Settlement volumes ± ·5 ml.

Volume of equal wet weight of unlike samples (Table VI).

Three subsamples, each of 40 gm. wet weight, were taken from a mixed phytoplankton sample, a mixed copepod sample and a mixed zoo-phytoplankton sample after each main sample had been filtered to displacement dryness. The displacement dryness. The displacement and settlement volumes of each of the nine subsamples were then determined.

TABLE VI.

Comparison of volumes from equal wet weights.

	Mixed diatoms.			Mixed copepod.			Mixed { zooplankton / phytoplankton.			
Wet weight	40·0	40·0	40·0	40·0	40·0	40·0	40·0	40·0	40·0	gm.
Displacement volume	37	37	37	37	37	37	37	37	37	ml.
Settlement volume	106	109	114	100	104	106	120	128	130	ml.
Ratio $\frac{Sv}{Dv}$	2·86	2·94	3·08	2·7	2·81	2·86	3·21	3·46	3·51	

Reading error { Displacement volume ± ·25 ml. / Settlement volume ± ·5 ml.

The results show:

(1) A constant relation (within the limits of the reading error) between the wet weight and the displacement volume.

(2) A variation of the settlement volume found for each subsample within a main sample.

(3) A barely significant difference between the ratios found for the mixed diatom and mixed copepod samples.

(4) A significant difference between the ratios found for the mixed zoo-phytoplankton and the other main samples.

Comparison of displacement and settlement volumes (Table VII).

Subsamples of different sizes were taken from main samples of mixed phytoplankton, mixed copepods (1 mm. and under), mixed zooplankton and phytoplankton, pure Salp swarm (*Salpa democratica*), and pure copepod (4 mm.) (*Calanus tonsus*). The volume of each subsample was determined by both the displacement and settlement methods and the results arrayed in Table VII. This shows:

(1) A fluctuating ratio $\frac{Sv}{Dv}$ for the Salp sample until a large volume is reached.

(2) A diminishing ratio $\frac{Sv}{Dv}$ for the other samples with increasing volumes.

(3) The range of ratios for each plankton composition gives a characteristic curve.

The behaviour of the Salp sample partly substantiates Redfield's opinion that the smaller ratio with large volumes is due to the tighter packing of large samples in the wet method (Redfield, 1941, 89). The range of ratios $\frac{Sv}{Dv}$ for each group of subsamples indicates the mechanical unreliability of the settlement method.

TABLE VII.

Comparison of Displacement and Settlement Volumes.

	D (ml.)	S (ml.)	Ratio $\frac{Sv}{Dv}$	D (ml.)	S (ml.)	Ratio $\frac{Sv}{Dv}$	D (ml.)	S (ml.)	Ratio $\frac{Sv}{Dv}$	D (ml.)	S (ml.)	Ratio $\frac{Sv}{Dv}$
Mixed diatoms	37	104	2·8	80	168	2·1	142	236	1·7	300	415	1·4
Mixed copepod 1 mm.	12	50	4·2	37	102	2·7	110	230	2·1	330	580	1·7
and under	19	69	3·6									
Zooplankton and Phyto-plankton	27	125	4·6	57	185	3·2	82	251	3·0	175	385	2·2
Salp swarm	24	62	2·6	48	131	2·8	72	180	2·5	182	400	2·2
(S. democratica)	184	520	2·8	352	1175	3·3	360	1150	3·2	1000	1800	1·8
Copepod swarm	6	30	5·0	34	130	3·8	40	142	3·5	72	223	3·1
(C. tonsus)												

Reading error { Displacement volumes ± ·5 cc. / Settlement volumes ± ·5 cc.

DISCUSSION.

The obvious results of the tests indicate that the settlement volume is not a reliable measure of plankton mass. This point is reasonably clear so that detailed analysis of the factors involved would be labouring the issue.

Further and more rigorous experiments are necessary to test the reliability of the displacement volume, but the indications from the tests made and from the relation existing between the displacement volume, water content, dry weight and ash weight, suggest that the displacement volume is a more useful measure of plankton mass than is the settlement volume.

It is possible that the measure may be a useful one to adopt as a routine in the preliminary analysis of plankton taken under standard conditions. It may be of value for making comparisons between areas, and between layers, and for examining seasonal and other trends provided that hauls are made with the same type of net used in the same manner.

It is not suggested that the routine should be used in place of the usual methods of analysis but purely as a time-saving preliminary which should yield useful information in conjunction with a biological appraisal of the material.

Consideration of the tables indicates that the practice in current use of assigning arbitrary values to the ratio $\frac{Sv}{Dv}$ is misleading and that detailed analysis of settlement volumes is not warranted.

B. Net Plankton Volumes

The net limitations, plankton swarm characteristics, etc., discussed by Bigelow and Sears (1939, 192–199, 221–228 *et seq.*), Clarke (1940, 250–255), Redfield (1941) and Riley (1941a) demand that net volume figures should be used for the purpose of general, and not detailed, comparisons. For detailed comparisons between different areas or periods of time the methods of Riley *et al.* must be used, productivity being regarded as rate of production, and production as quantity produced during a given unit of time expressed in a standard measure.

Plankton net tows are simply the records of the amount of plankton captured by a certain type of net under certain conditions, giving a possible measure of the standing crop (Redfield, 1941, 102) of certain organisms. In comparing large areas or in assessing trends over periods of time they may provide a useful index but they are not measures of productivity or production in the sense of Riley (1941).

Since the plankton population is the resultant of a recurring series of events, one use of such an index as the displacement net volume is that, combined with a knowledge of the organisms concerned, it gives a rapidly estimated rough measure of a change. For example, if the tow-nettings expressed in Tables XIII and XIV were continued systematically at the Cronulla Station, N.S.W., a fairly reliable quantitative measure of the amplitude of the salp invasion should emerge. Similarly from the vertical series of the B.A.N.Z.A.R.E. plankton the measure allows a useful comparison between the various layers.

Net Plankton Volumes, B.A.N.Z.A.R.E.

In Tables VIII, IX, X, and XI the displacement volume values of certain of the B.A.N.Z.A.R.E. N 70 hauls have been recorded and reduced to common measures.

(1) Volume of net plankton per 50 metres of haul.
(2) Volume of net plankton per cubic metre. (Bigelow and Sears, 1939, 197).
(3) Volume of net plankton per metre squared of surface over a column of 100 metres. (Redfield, 1941, 87, 89).

For the present, Tables VIII, IX and XI are given to enable plankton workers to compare the data with work they may have in hand. The tables will be discussed in detail in a later paper dealing with the composition of the net plankton of the 1930–31 cruise.

Table VIII.

B.A.N.Z.A.R.E.

Displacement Volumes. N 70 Vertical hauls (ml.).

Raw Data.

Sta.	Lat. ° S.	Long. ° E.	50–0	100–50	250–100	500–250	750–500	1,000–750	Sum.
				DEEP STATIONS.					
75	36	114	2·0	3·5	2·5	2·0	3·0	2·0	15·0
74	37	110	2·0	2·0	1·0	2·0	4·0	5·0	16·0
72	40	104	2·0	1·0	4·0	5·0	5·0	5·0	22·0
114	41	148	3·0	6·0	0·5	4·0	3·0	3·0	19·5
70	42	96	3·0	5·0	5·0	7·0	4·0	6·5	30·5
111	44	143	1·0	1·0	3·0	2·0	0·5	1·0	8·5
77	44	147	2·5	2·0	1·5	0·5	(a)	3·5	—
68	45	87	2·0	0·5	1·5	2·0	5·0	5·0	16·0
110	48	114	5·0	2·0	2·0	2·5	3·0	3·0	17·5
78	48	146	(a)	(a)	5·0	25·0	7·5	3·0	—
109	51	101	0·5	3·0	5·0	9·0	12·0	(a)	—
79	52	152	(a)	(a)	15·0	45·0	50·0	3·0	—
84	61	162	15·0	5·0	5·0	5·0	2·5	2·0	34·5
86	63	164	18·0	4·0	6·5	2·5	3·0	1·5	35·5
92	64	116	0·5	1·0	1·0	2·0	1·5	1·0	7·0
95	64	113	8·0	2·0	2·0	3·0	3·0	2·0	20·0
91	64	124	5·5	2·0	1·0	0·5	0·5	0·5	13·5
99	64	91	13·0	8·0	3·0	1·5	3·0	1·5	30·0
101	65	85	120	10·0	2·5	1·0	1·0	0·5	135
87	65	147	7·5	2·0	1·0	1·5	1·0	0·5	13·5
85	65	178	10·0	6·5	3·5	3·0	1·0	2·0	26·0
102	66	75	3·0	10·0	4·0	2·0	1·0	3·0	23·0
				SHELF STATIONS.					
100	65	89	6·5	4·0	5·0				
89	66	141	14·5	9·0					
107	66	62	62	15·0	6·0				
104	68	70	7·0	2·0	2·0				

(a) no sample.

Table IX.

B.A.N.Z.A.R.E.

Hauls expressed as Displacement Volumes per 50 metre of haul (ml.).

Station.	50–0	100–0	250–100	500–250	750–500	1,000–750
			DEEP STATIONS.			
75	2·0	3·5	0·8	0·4	0·6	0·4
74	2·0	2·0	0·3	0·4	0·8	1·0
73	2·0	1·0	1·3	1·0	1·0	1·0
114	3·0	6·0	0·2	0·8	0·6	0·6
70	3·0	5·0	1·6	1·4	0·8	1·3
111	1·0	1·0	1·0	0·4	0·1	0·2
77	2·5	2·0	0·5	0·1	—	0·7
68	2·0	0·5	0·5	0·8	1·0	1·0
110	5·0	2·0	0·6	0·5	0·6	0·6
78	—	—	1·6	5·0	1·5	0·6
109	0·5	3·0	1·6	1·9	2·4	—
79	—	—	5·0	9·0	10·0	0·6
84	15·0	5·0	1·6	1·0	0·5	0·4
86	18·0	4·0	2·1	0·5	0·6	0·3
92	0·5	1·0	0·3	0·4	0·3	0·2
95	8·0	2·0	0·6	0·6	0·6	0·4
91	5·5	2·0	0·3	0·1	0·1	0·1
99	13·0	8·0	1·0	0·3	0·6	0·3
101	12·0	10·0	0·8	0·2	0·2	0·1
87	7·5	2·0	0·3	0·3	0·2	0·1
102	3·0	10·0	1·3	0·4	0·2	0·6
			SHELF STATIONS.			
100	6·5	4·0	1·6			
89	14·5	9·0	—			
107	62·0	15·0	2·0			
104	7·0	2·0	0·6			

TABLE X.

B.A.N.Z.A.R.E.

Ocean Plankton—N 70 Vertical hauls—Comparative Displacement Volumes (ml.).

Depth metres.	Total vol.	No. of hauls.	Average vol. per haul.	Average vol. per 50 metres.	Vol. per M^3.	Vol. per M^2 of surface.
50–0	103·5	19	5·4	5·4	0·280	28
100–50	66·5	19	3·5	3·5	0·190	19
250–100	58·0	20	2·9	0·97	0·053	5·3
500–250	82·0	20	4·1	0·81	0·042	4·2
750–500	63·5	19	3·3	0·66	0·034	3·4
1,000–750	51·0	19	2·7	0·54	0·028	2·8

In Table X the results of the N 70 Vertical Ocean Hauls are summarized. The findings of Jesperson (1935) for Ocean waters and Thompson (1942) for Shelf waters are confirmed. The bulk (75 per cent.) of the net plankton was taken in the upper 100 metres. Allowing for sampling and net error the results from the 250–100 metre, 500–250 metre, and 750–500 metre layers apparently do not differ greatly among themselves with volume about one-sixth of that of the 50–0 metre layer and about one-fourth of that of the 100–50 metre layer. The results of the 1,000–750 metre hauls, while lower in volume than the other layers are surprisingly high, little phytoplankton was present but the zooplankton was in good condition.

TABLE XI.

B.A.N.Z.A.R.E.

Displacement Volumes (ml.). N 70 oblique.

Sta.	Lat. °S.	Long. °E.	Depth Metres.	Time Hrs.	Duration Mins.	Vol. ml.	Vol. per 50 Metres ml.	Vol. per M^3 ml.	Vol. per M^2 of surface. ml.
				DEEP STATIONS					
75	36	114	150	14·03	20	18	0·9	·046	4·6
74	37	110	150	16·35	20	27	1·35	·07	7
73	38	33	112	15·15	20	29	1·45	·074	7·4
72	40	104	83	19·23	20	25	1·25	·077	7·7
114	41	148	109	18·40	20	14	0·7	·036	3·6
70	42	96	150	14·05	20	31	1·55	·087	8·7
111	44	143	90	08·22	20	25	1·25	·077	7·7
65	47	76	128	09·45	18	125	6·25	·324	32·4
110	48	114	96	18·08	20	55	2·75	·143	14·3
109	51	101	71	21·55	20	54	2·7	·14	14
46	55	55	175	14·24	21	400	20·0	1·04	104
84	61	162	200	14·10	20	65	3·25	·169	16·9
22	61	77	170	20·00	20	150	7·5	·39	39
45	63	54	100	13·58	20	35	1·75	·091	9·1
92	64	116	128	16·20	20	35	1·75	·091	9·1
24	64	79	135	17·55	20	225	11·25	·58	58
85	65	178	120	14·38	20	175	8·75	·44	44
87	65	147	183	13·54	20	25	1·25	·077	7·7
96	65	109	93	11·00	20	250	12·5	·65	65
31	66	65	91	09·53	20	32	1·8	·093	9·3
33	66	61	125	17·20	20	300	15·0	·78	78
37	66	45	147	18·25	20	185	9·25	·46	46
					Average	(104)	(5·2)	(·27)	(27)
				SHELF STATIONS					
76	35	118	60	16·50	20	20	1·0	·082	8·2
41	65	53	130	21·19	20	150	7·5	·39	39
89	66	141	111	23·15	20	300	15·0	·78	78

While the calculated volumes are not directly comparable with those recorded by Thompson (1942, 35) the results shown in Tables VIII, IX and X well support his suggestion of a rather even distribution of plankton at depth.

It will be noticed that the volumes of net plankton per 50 metres of haul for depths below 250 metres fall into two series, with those from the latitudes of the sixties significantly lower than those further north. The data become limited, but with the Antarctic recordings omitted, the values of the 1,000–750 metre layer more nearly approach those from the intermediate layers in the warmer waters.

The Antarctic ocean series tends to confirm the suggestion of Mackintosh (1937) that the Antarctic macroplankton is mainly concentrated in the surface layers in summer, as 88 per cent. of the net plankton of the Antarctic vertical hauls (see Tables VIII and IX) was obtained from the 100–0 metre level.

C. Comparison of Net Volumes

The Cronulla (C.S.I.R. Division of Fisheries) and B.A.N.Z.A.R.E. net hauls were made with the same type of nets (N 70 Discovery type, 70 cm. diameter, mesh 40 to the linear inch in forepart, 74 to the linear inch in hindpart) and the volumes assessed with a constant technique. Accordingly some degree of comparison is possible between the sets of values.

The Cronulla results for N 70, 15 minute horizontal tows are recorded in Tables XII to XIV. These results will be discussed in detail at a later date, but are given here for general comparison.

Table XII records the results of horizontal tows carried out by Mr. D. Rochford, Hydrologist, C.S.I.R. Division of Fisheries, during the daylight hours of three consecutive days in July, 1942, at the Cronulla onshore Station, New South Wales. It gives some measure of the net plankton volume during a period of plankton dearth. (Some of the volume changes recorded are due to real changes in the composition of the plankton so that the results are only a partial measure of net reliability.)

Table XII.

Displacement Plankton Volumes. July, 1942.

C.S.I.R. Division of Fisheries, Cronulla on-shore Station.

N 70. 15 minutes. 600 metres. Surface horizontal haul.

Date.	Time.	Vol. (ml.)	Vol. per 50 metres.	Vol. per M^3	Vol. per M^2 of surface.	Dominant.
17/7/1942	10·00	0·2	·016	·0009	·09	Crustacea
17/7/1942	11·00	0·2	·016	·0009	·09	Crustacea
17/7/1942	13·00	0·4	·033	·017	1·7	Crustacea
17/7/1941	14·00	1·0	·08	·004	0·4	Crustacea
17/7/1942	15·00	0·5	·042	·0021	0·21	Crustacea
18/7/1942	8·00	3·0	·25	·013	1·3	Crustacea
18/7/1942	9·00	1·0	·08	·004	0·4	Crustacea
18/7/1942	10·00	0·5	·042	·0021	0·21	Crustacea
18/7/1942	11·00	0·5	·042	·0021	0·21	Crustacea
18/7/1942	12·00	0·5	·042	·0021	0·21	Crustacea
18/7/1942	13·00	0·5	·042	·0021	0·21	Crustacea
18/7/1942	14·00	0·5	·042	·0021	0·21	Crustacea
18/7/1942	15·00	0·8	·066	·0034	0·34	Crustacea
19/7/1942	8·00	2·0	·16	·009	0·9	Crustacea
19/7/1942	9·00	4·0	·33	·017	1·7	Crustacea
19/7/1942	10·00	0·5	·042	·0021	0·21	Crustacea
19/7/1942	11·00	1·0	·08	·004	0·4	Crustacea
19/7/1942	12·00	3·0	·25	·013	1·3	Crustacea
19/7/1942	13·00	3·0	·25	·013	1·3	Crustacea
19/7/1942	14·00	2·0	·16	·009	0·9	Crustacea
Average (ml.)		(1·25)	(·104)	(·0052)	(·52)	

Table XIII.

Displacement Plankton Volumes, 1943.

C.S.I.R. Division of Fisheries, Cronulla on-shore Station.

N 70. 15 minutes. 600 metres. Surface horizontal haul.

Month.	Vol. (ml.)	Vol. per 50 metres.	Vol. per M^3.	Vol. per M^2 of surface.	Dominant.
January	28	2·3	·12	12	Crustacea
January	18	1·5	·077	7·7	Crustacea
February	10	·8	·043	4·3	Crustacea
February	8	·7	·034	3·4	Crustacea
March	7	·6	·03	3·0	Crustacea
March	6	·5	·026	2·6	Crustacea
April	6	·5	·026	2·6	Crustacea
April	4	·3	·017	1·7	Crustacea
April	3	·25	·013	1·3	Crustacea
May	2	·2	·009	0·9	Crustacea
May	7	·6	·03	3·0	Crustacea
June	10	·8	·043	4·3	Crustacea
June	5	·4	·021	2·1	Crustacea
June	12	1·0	·053	5·3	Diatoms
June	5	·4	·021	2·1	Diatoms
July	2	·2	·009	0·9	Diatoms
July	18	1·5	·077	7·7	Diatoms
July	4	·3	·017	1·7	Diatoms
July	2	·2	·009	·9	Diatoms
July	6	·5	·026	2·6	Tunicates
July	4	·3	·017	1·7	Tunicates
August	10	·8	·043	4·3	Tunicates
August	10	·8	·043	4·3	Tunicates
August	48	4·0	·2	20	Tunicates
August	32	2·6	·138	13·8	Tunicates
August	12	1·0	·053	5·3	Tunicates
September	40	3·3	·17	17	Tunicates
September	40	3·3	·17	17	Tunicates
September	12	1·0	·053	5·3	Tunicates
September	8	·7	·034	3·4	Crustacea
September	5	·4	·021	2·1	Crustacea
September	8	·7	·034	3·4	Crustacea
October	11	·9	·048	4·8	Crustacea
October	6	·5	·026	2·6	Crustacea
October	8	·7	·034	3·4	Crustacea
October	1	·1	·004	0·4	Crustacea
October	1	·1	·004	0·4	Crustacea
November	2	·2	·009	0·9	Crustacea
November	18	1·5	·077	7·7	Crustacea
November	9	·75	·039	3·9	Crustacea
November	11	·9	·048	4·8	Crustacea
December	2	·2	·009	0·9	Crustacea
December	6	·5	·039	3·9	Crustacea
December	8	·7	·034	3·4	Crustacea

Tables XIII and XIV record the N 70 net plankton volumes of the Cronulla Station for 1943 and 1944 (the monthly averages are recorded as part of Table XV). In addition to showing the overall net plankton level for the stations, they demonstrate a difference in the level of the net plankton for each year, and show the sharp increase due to the salp invasion on the coast together with their subsequent disintegration. (Test hauls at the beginning of the period showed that the invasion was almost simultaneous over several hundred miles of coast, at least from the region of Sydney, N.S.W., to Eden in the south of that State).

While the tables do not give more than an indication of productivity or production in the sense of Riley (1941), they show the trend of events during the two years.

Table XIV.

Displacement Plankton Volumes, 1944.

C.S.I.R. Division of Fisheries. Cronulla on-shore Station.

N 70. 15 minutes. 600 metres. Surface horizontal haul.

Month.	Vol. (ml.)	Vol. per 50 metres.	Vol. per M^3.	Vol. per M^2 of surface.	Dominant.
January	14	1·2	·060	6·0	Crustacea
January	18	1·5	·077	7·7	Crustacea
January	14	1·2	·060	6·0	Crustacea
January	15	1·25	·064	6·4	Crustacea
January	15	1·25	·064	6·4	Crustacea
January	18	1·5	·077	7·7	Crustacea
January	14	1·2	·060	6·0	Crustacea
February	16	1·3	·069	6·9	Crustacea
February	22	1·8	·094	9·4	Crustacea
February	22	1·8	·094	9·4	Crustacea
March	8	·7	·034	3·4	Crustacea
March	9	·75	·038	3·8	Crustacea
March	7	·6	·030	3·0	Crustacea
April	10	·8	·043	4·3	Crustacea
April	9	·75	·038	3·8	Crustacea
April	7	·6	·030	3·0	Crustacea
May	8	·7	·034	3·4	Crustacea
May	4	·3	·017	1·7	Diatoms
May	6	·5	·026	2·6	Diatoms
May	11	·9	·048	4·8	Diatoms
May	6	·5	·026	2·6	Diatoms
May	11	·9	·048	4·8	Diatoms
June	4	·3	·017	1·7	Diatoms
June	6	·5	·026	2·6	Diatoms
June	4	·3	·017	1·7	Diatoms
June	5	·4	·021	2·1	Diatoms
July	12	1·0	·053	5·3	Crustacea
July	14	1·2	·060	6·0	Crustacea
July	2	·2	·009	0·9	Crustacea
August	3	·25	·013	1·3	Crustacea
August	6	·5	·026	2·6	Crustacea
August	30	2·5	·129	12·9	Tunicates
August	352	29·3	1·514	151·4	Tunicates
September	184	15·3	·791	79·1	Tunicates
September	360	30·0	1·55	155	Tunicates
September	350	29·2	1·505	150·5	Tunicates
September	1,000	83·3	4·3	430	Tunicates
October	120	10·0	·526	52·6	Tunicates
October	90	7·5	·387	38·7	Tunicates
October	60	5·0	·258	25·8	Tunicates
October	160	13·3	·688	68·8	Tunicates
October	120	10·0	·526	52·6	Tunicates
October	72	6·0	·311	31·1	Tunicates
November	30	2·5	·129	12·9	Crustacea
November	41	3·4	·176	17·6	Crustacea
November	25	2·1	·106	10·6	Crustacea
November	21	1·75	·090	9·0	Crustacea
November	6	·5	·026	2·6	Crustacea
November	6	·5	·026	2·6	Crustacea
December	22	1·8	·095	9·5	Tunicates
December	60	5·0	·26	26	Tunicates
December	8	·7	·034	3·4	Tunicates

Table XV, adapted from Bigelow and Sears (1939, 223 and 225), omitting settlement volume records and adding monthly averages from the Cronulla Station, lists the published displacement net volumes. Those from the B.A.N.Z.A.R.E. for selected localities from Australia to the Antarctic are tabulated in Table XVI.

Table XV.

Volume of Plankton. All Oceans.

(Displacement Volumes. Averages.)

Locality.	Season or Month.	Author.	Vol. per M^3 (ml.)	Vol. per M^2 of surface. (ml.)	Method.
Cape Cod to Chesapeake Bay	Feb., 1930–32	Bigelow and Sears (1939)	0·4	40	Net, 1 metre and ½ metre, 29–38 meshes to 48–54 meshes.
	April, 1929–30		0·5	50	
	May, 1929–32		0·8	80	
	June, 1929–32		0·7	70	
	July, 1929–31		0·8	80	
	October, 1931		0·4	40	
Gulf of Maine	April, 1932	Fish and Johnson (1937)	0·7	70	Net.
	May, 1932		0·34	34	
	June, 1932		0·21	21	
	Aug.–Sept., 1932		0·16	16	
	September, 1933	Redfield (1941)	0·21	21	Net, 1·5 m., Heligoland net, 38 meshes to 1 in.
	October, 1933		0·13	13	
	December, 1933		0·17	17	
	January, 1934		0·12	12	
	March, 1934		0·05	5	
	April–May, 1934		0·16	16	
	May–June, 1934		0·26	26	
	June–July, 1934		0·32	32	
	September, 1934		0·5	50	
Bay of Fundy	April, 1932	Fish and Johnson (1937)	0·04	4	Net.
	May, 1932		0·19	19	
	June, 1932		0·2	20	
	Aug.–Sept., 1932		0·09	9	
Iceland; Faroes		Jespersen (1923)	0·84	84	Stramin net. (Vol. by drainage.)
North Sea		Jespersen	0·013	1·3	Stramin net. (Vol. by drainage.)
Off Cuba	May, 1939	Riley (1939)	0·02	2	Net.
Gulf Stream			0·05	5	
Off Florida			0·07	7	
Off Woods Hole (shelf)	June, 1939		4·3	430	
			8·1	810	
Cronulla, N.S.W. Shelf Station	July, 1942	*Mihi*, Table XII	0·0052	0·52	N 70 Discovery pattern net, vertical.
Cronulla, N.S.W. Shelf Station	January, 1943	*Mihi*, Table XIII	0·098	9·85	N 70 Discovery pattern net, horizontal.
	February, 1943		0·038	3·85	
	March, 1943		0·029	2·9	
	April, 1943		0·019	1·87	
	May, 1943		0·019	1·95	
	June, 1943		0·034	3·45	
	July, 1943		0·026	2·6	
	August, 1943		0·09	9·54	
	September, 1943		0·06	6·0	
	October, 1943		0·023	2·3	
	November, 1943		0·043	4·3	
	December, 1943		0·036	3·65	
	January, 1944	*Mihi*, Table XIV	0·06	6·6	
	February, 1944		0·086	8·6	
	March, 1944		0·034	3·4	
	April, 1944		0·037	3·7	
	May, 1944		0·033	3·3	
	June, 1944		0·02	2·0	
	July, 1944		0·04	4·05	
	August, 1944		0·42	42	
	September, 1944		1·72	172	
	October, 1944		0·45	44·9	
	November, 1944		0·092	9·2	
	December, 1944		0·13	13	

Comparisons are difficult owing to the different types of nets used but, in general, the Sub-antarctic net plankton values obtained by the B.A.N.Z.A.R.E. in non-Australian waters are reasonably comparable with those obtained from Cape Cod, Chesapeake Bay, Gulf of Maine, Nova Scotia and Iceland.

The Cronulla and B.A.N.Z.A.R.E. Australian values are much less than those obtained for the Antarctic and are perhaps comparable with those of the Gulf Stream or the Bay of Fundy or with those of the months showing lesser values in the Gulf of Maine. It is interesting to note that the Cronulla and B.A.N.Z.A.R.E. Australian figures lend point to the numerical comparison made by Russell (1934, 181) between the Great Barrier Reef Lagoon and the English Channel.

The Cronulla values fall into two series, the salp and non-salp periods. The salp period for 1944 gives volumes comparable with those of the richest areas but the non-salp volumes are low. A feature of the readings is the high degree of fluctuation.

The point has been stressed already, but, since the plankton sampled by the net is the resultant of many factors (see Russell, 1934, 180–185; Harvey *et al.* 1935, 407/441; Hardy, 1935, 276–364, and *lit.*) deductions as to fishery potentialities drawn from comparisons such as these must be modified by both local knowledge and a consideration of the other factors involved, particularly in neritic waters. For example, in considering the Cronulla figures it is necessary to appreciate that as the station site was selected in order to give as clear a picture as possible of the cyclical changes in the area, an eddy zone of much higher plankton concentration (net volumes 3 to 4 times higher) further south was not occupied since it was felt that the normal cylical changes and zooplankton associations would be interfered with there to some extent. For the same reason the hauls were made between the hours of 9.00 and 12.00 in order to avoid complicating the picture with possible night rises of the trawl zone animals. [Other investigations (unpublished), using nets modified from Hickling (1925), were made of this zone at Cronulla, and the results showed a fair comparison with those obtained in the English Channel, *Nyctiphanes australis* being the major species.]

B.A.N.Z.A.R.E. Localities

In Table XVI the unit net plankton volumes of selected B.A.N.Z.A.R.E. localities have been listed. They must be used with caution as for the most part they represent single hauls. The upper 100 metres only are considered for the vertical hauls; the range of the oblique hauls can be read from Table XI.

While the values are for the most part high their changes (above the catching error) suggest a patchiness in distribution similar to that described by Gunther and Hardy (1935, 254) for the South Georgia region. The hauls are daytime hauls, so that extremes of vertical migration should be ruled out.

With regard to the standing crop it is difficult to compare the areas in terms of net volumes with those covered by the "Discovery" cruises but, to anticipate further sections of this work, the plankton net volumes plus phytoplankton and zooplankton counts suggest the comparison of shelf waters of the area from Enderby Land to Adèlie Land with possibly the South Georgia area (Gunther and Hardy, 1935), and certainly with the Weddell Sea area on equal terms. The open

ocean records from Princess Elizabeth Land to Adèlie Land follow the same level. The low values of Ocean net plankton off Enderby Land and MacRobertson Land are accompanied by real changes in the plankton. In this regard Sverdrup's suggestion of ascending motion (Sverdrup, 1940, 121) over some part of this general area is of interest.

TABLE XVI.

Unit Volumes—B.A.N.Z.A.R.E. Localities, Net Plankton.

N 70 Discovery Net. Oblique and vertical hauls.

Locality.	Stations.	Type of haul.	Month.	Vol. per M^3 (ml.)	Vol. per M^2 of surface. (ml.)
		OCEAN.			
Southern Indian Ocean	74, 75	Vertical	March, 1930	0·123	12·3
Southern Indian Ocean	74, 75	Oblique	March, 1930	0·058	5·8
North-eastern Tasmania	114	Vertical	March, 1931	0·231	23·1
North-eastern Tasmania	114	Oblique	March, 1931	0·036	3·6
South of Tasmania	77	Vertical	November, 1930	0·117	11·7
South of Tasmania	111	Oblique	March, 1931	0·077	7·7
Open Southern Ocean	68, 109, 110	Vertical	March, 1930–31	0·115	11·5
Antarctic Ocean					
Enderby Land	45	Oblique	January, 1930	0·091	9·1
MacRobertson Land	31	Oblique	December, 1929	0·093	9·3
Princess Elizabeth Land	102	Vertical	February, 1931	0·34	34
Kaiser Wilhelm Land	99	Vertical	February, 1931	0·533	53·3
Banzare Land	91	Vertical	January, 1931	0·192	19·2
Adèlie Land	87	Vertical	December, 1931	0·249	24·9
Scott Island	85	Vertical	December, 1930	0·414	41·4
		SHELF.			
Southern Indian Ocean	76	Oblique	March, 1930	0·05	5
Antarctic Ocean	41	Oblique			
Enderby Land			January, 1930	0·39	39
Kemp Land	33	Oblique	January, 1930	0·78	78
MacRobertson Land	107	Vertical	February, 1931	1·999	199·9
MacRobertson Land	107	Oblique	February, 1931	0·449	44·9
Mackenzie Sea	104	Vertical	February, 1931	0·226	22·6
Kaiser Wilhelm Land	100	Vertical	February, 1931	0·277	27·7
Adèlie Land	89	Vertical	January, 1931	0·606	60·6
	89	Oblique	January, 1931	0·78	78

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